



US009906036B2

(12) **United States Patent**
Chapman

(10) **Patent No.:** **US 9,906,036 B2**
(45) **Date of Patent:** **Feb. 27, 2018**

(54) **ALTERNATIVE SOURCE MODULE ARRAY CHARACTERIZATION**

(71) Applicant: **SunPower Corporation**, San Jose, CA (US)

(72) Inventor: **Patrick Chapman**, Austin, TX (US)

(73) Assignee: **SunPower Corporation**, San Jose, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 346 days.

(21) Appl. No.: **14/720,445**

(22) Filed: **May 22, 2015**

(65) **Prior Publication Data**
US 2015/0340868 A1 Nov. 26, 2015

Related U.S. Application Data

(60) Provisional application No. 62/002,885, filed on May 25, 2014.

(51) **Int. Cl.**
H02J 1/00 (2006.01)
H02J 3/38 (2006.01)
H02M 7/44 (2006.01)
G08C 19/02 (2006.01)

(52) **U.S. Cl.**
CPC **H02J 3/383** (2013.01); **G08C 19/02** (2013.01); **H02M 7/44** (2013.01); **Y02E 10/563** (2013.01); **Y10T 307/707** (2015.04)

(58) **Field of Classification Search**
CPC H02J 3/383; H02M 7/44; Y02E 10/563; Y10T 307/707; G08C 19/02
USPC 307/82
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,666,561 B2 * 3/2014 Fornage H02J 3/383 363/95
2011/0172842 A1 * 7/2011 Makhota H01L 31/02021 700/292
2012/0158197 A1 6/2012 Hinman et al.
2012/0275196 A1 11/2012 Chapman et al.
(Continued)

FOREIGN PATENT DOCUMENTS

CN 102158129 A 8/2011
CN 103475019 A 12/2013
(Continued)

OTHER PUBLICATIONS

PCT/US2015/032281 International Search Report, dated Aug. 27, 2015, 3 pages.
(Continued)

Primary Examiner — Jared Fureman

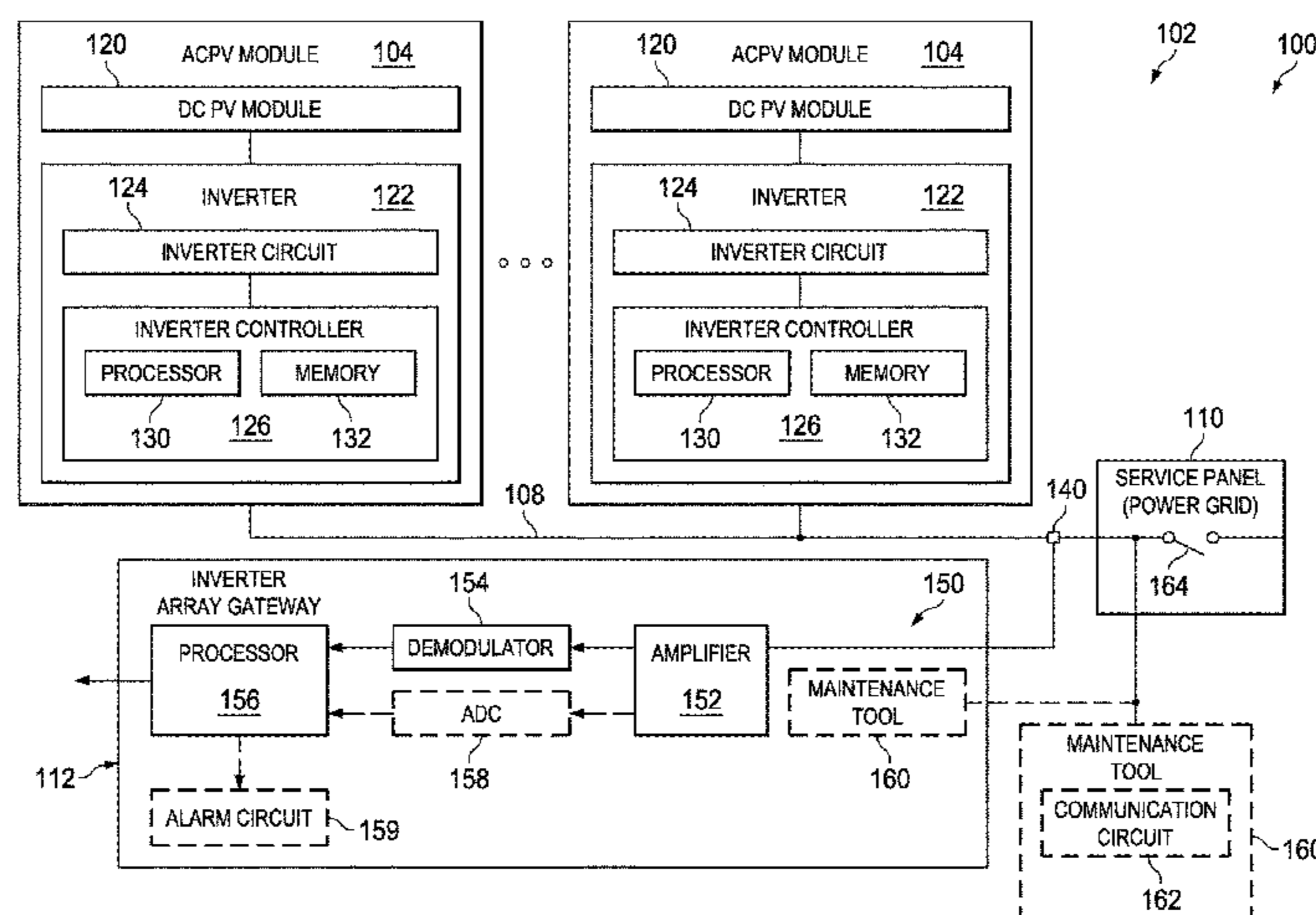
Assistant Examiner — Duc M Pham

(74) *Attorney, Agent, or Firm* — Boisbrun Hofman, PLLC

(57) **ABSTRACT**

A system and method for mapping relative positions of a plurality of alternative energy source modules. In one embodiment, the method includes injecting a first contribution current into a power grid by a first alternative energy source module of the plurality of alternative energy source modules and determining an output voltage for each of the plurality of alternative energy source modules. The method also includes constructing a data structure of the relative positions of the plurality of alternative energy source modules employing the output voltage for ones of the plurality of alternative energy source modules.

20 Claims, 8 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

2012/0306515 A1* 12/2012 Barnes H02J 3/383
324/707
2013/0285457 A1 10/2013 Kepley
2015/0028682 A1* 1/2015 Jean H02J 1/00
307/80

FOREIGN PATENT DOCUMENTS

EP 2725372 A1 4/2014
JP 2000217259 A 8/2008
KR 20130079015 A 7/2013
WO 2008144540 A1 11/2008
WO 2015183751 A1 3/2015

OTHER PUBLICATIONS

EP Application No. 15800118.0-1804 dated Feb. 22, 2017, European Search Report, 7 pages.

* cited by examiner

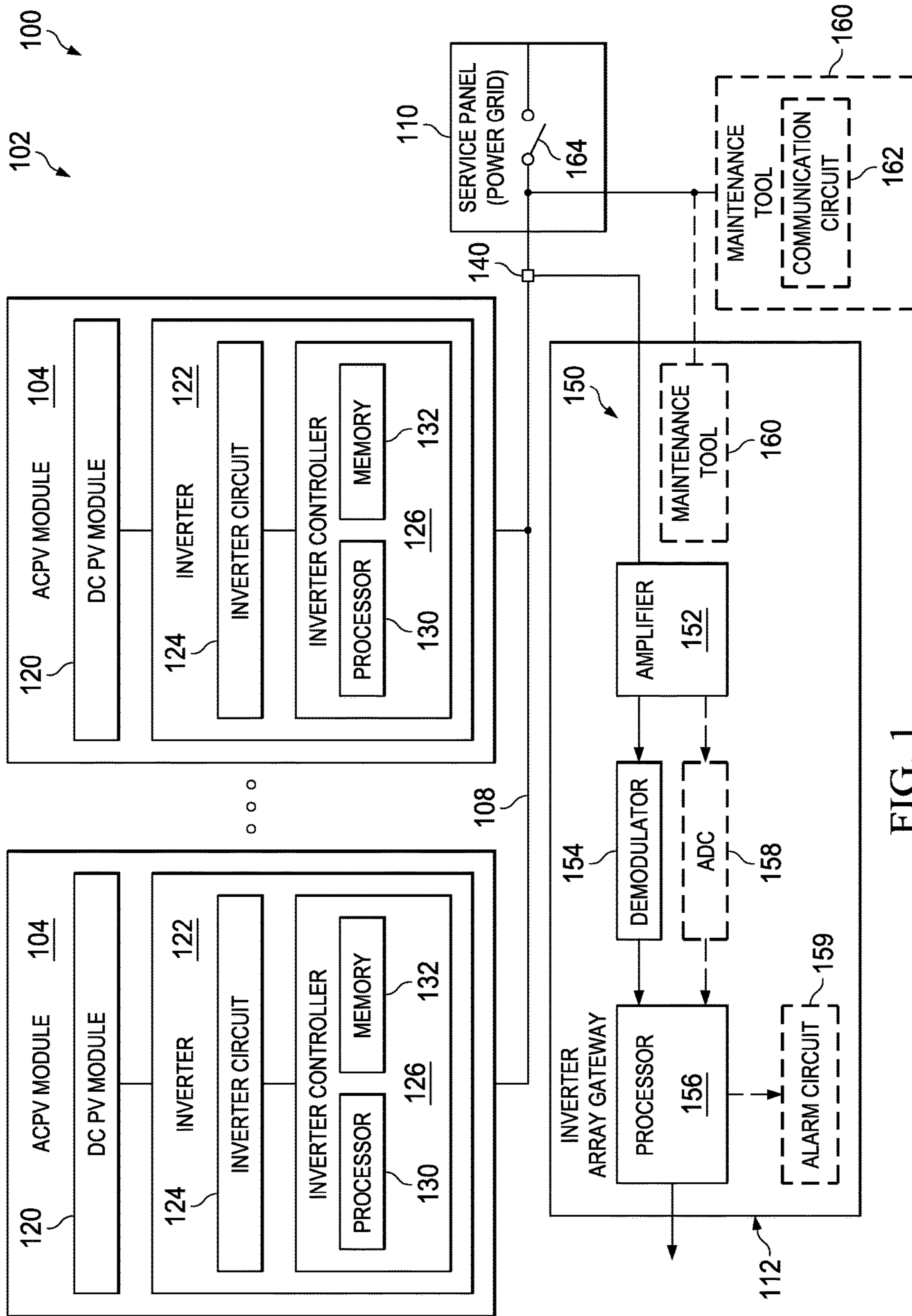


FIG. 1

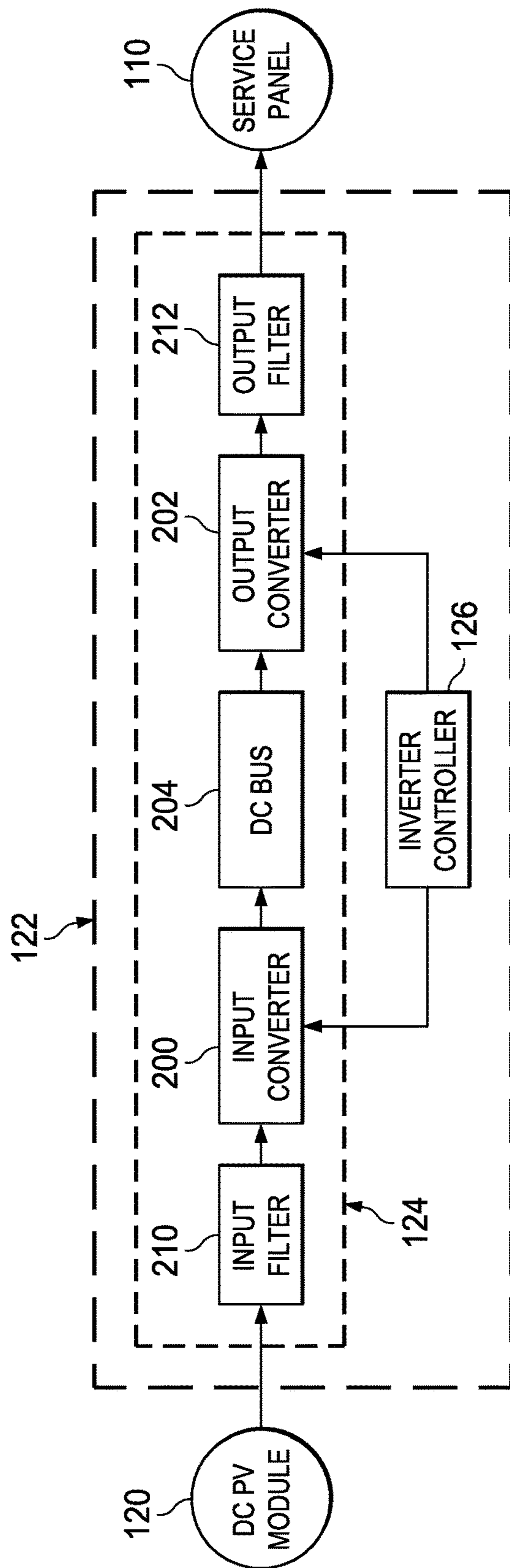


FIG. 2

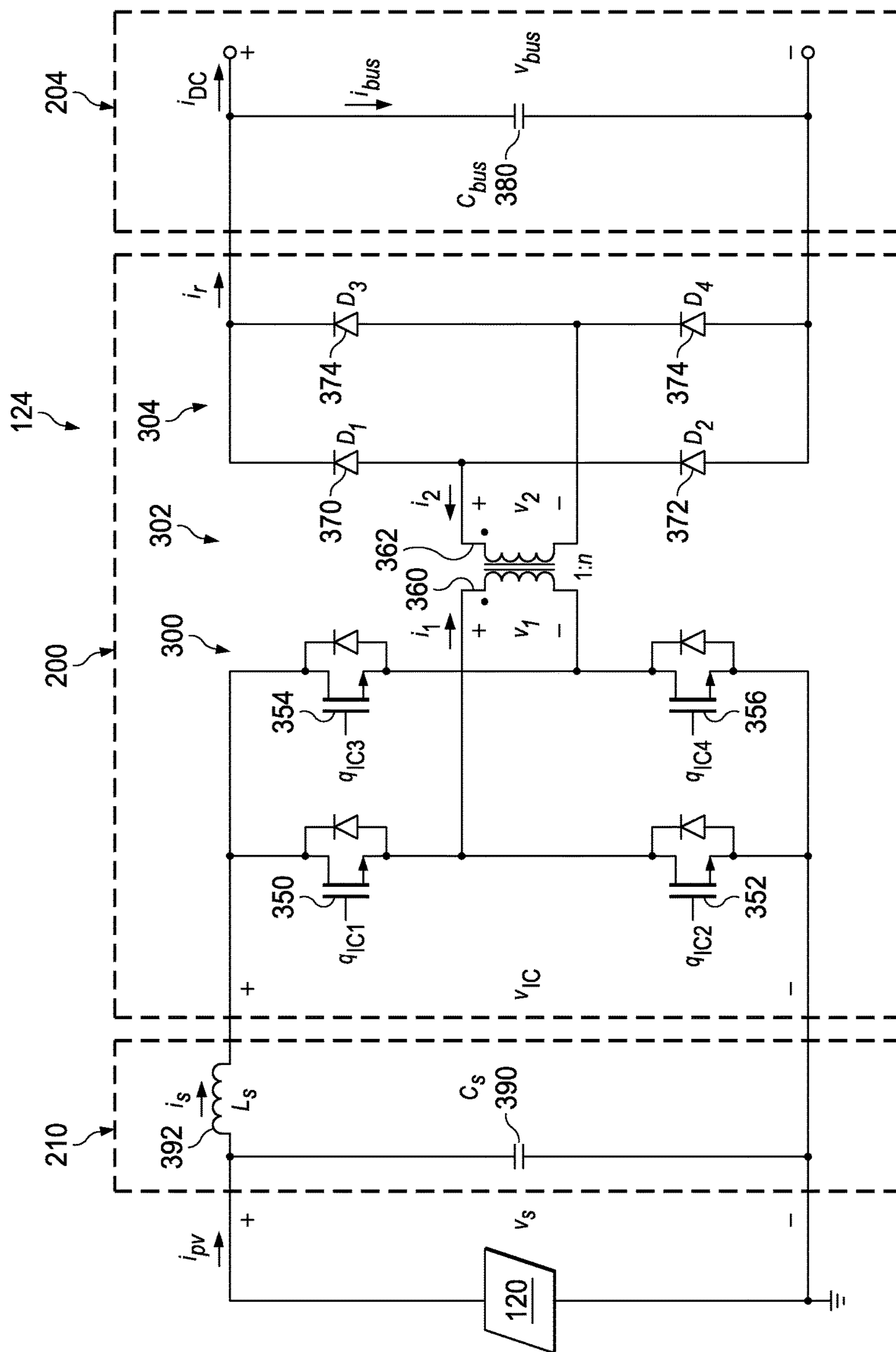


FIG. 3

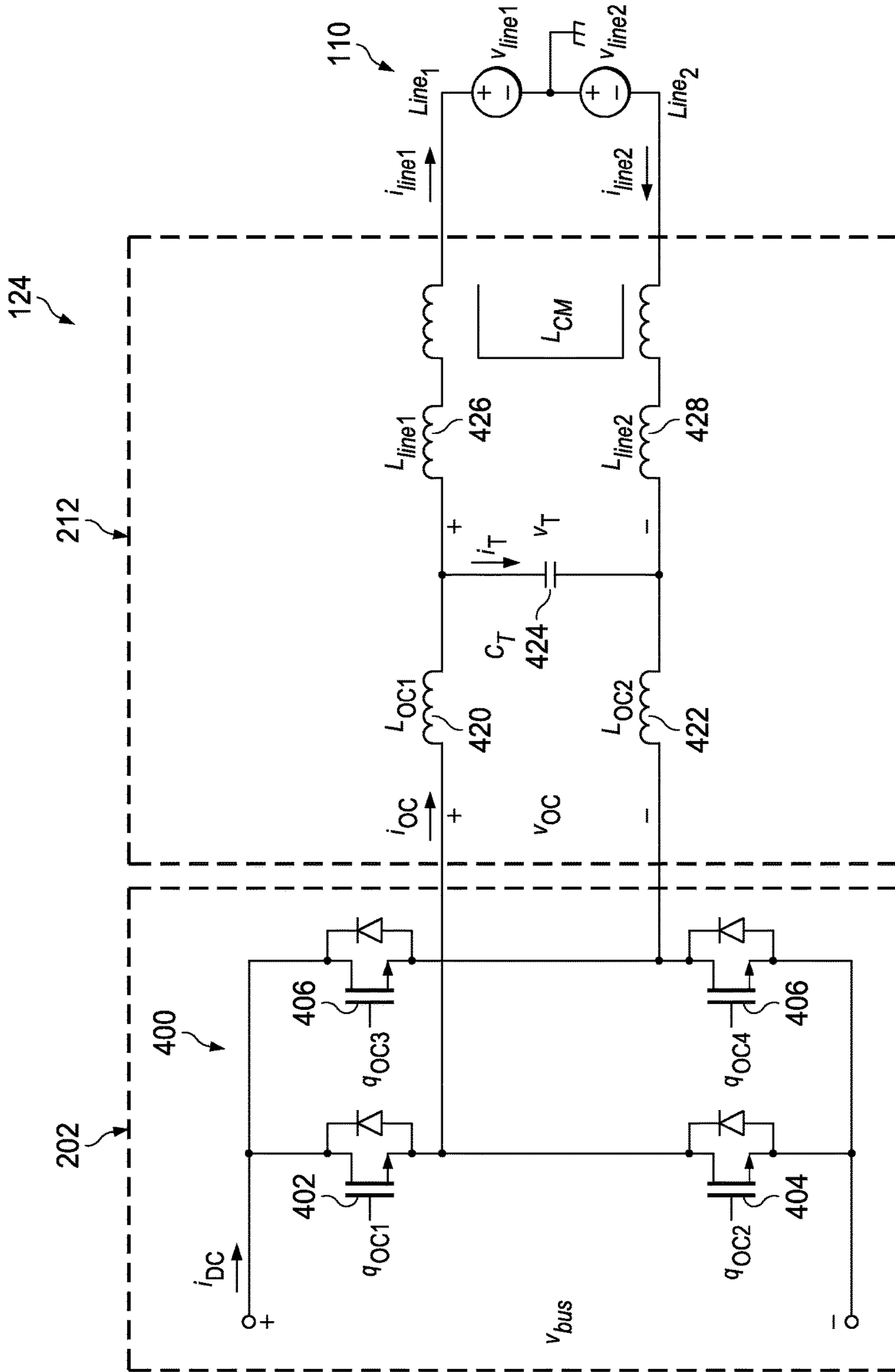


FIG. 4

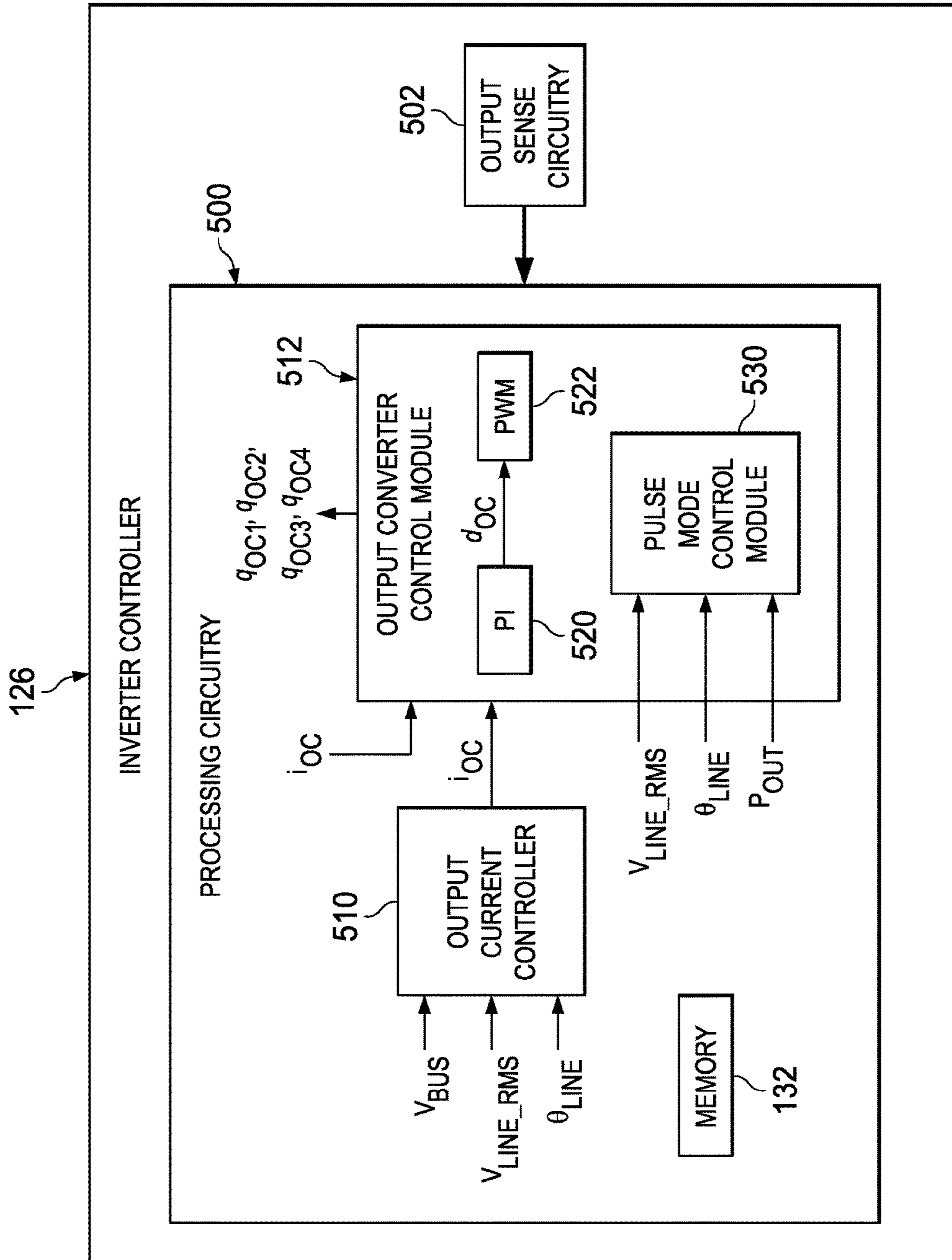


FIG. 5

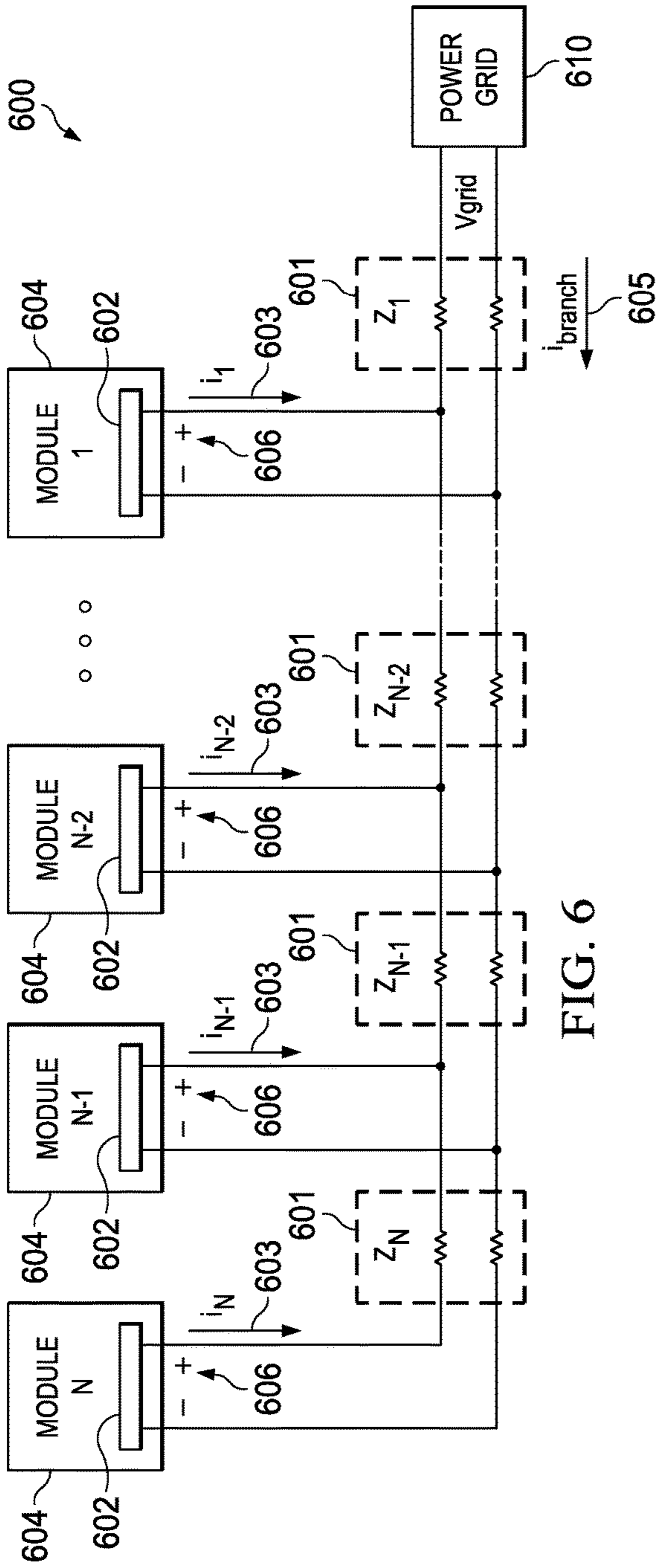


FIG. 6

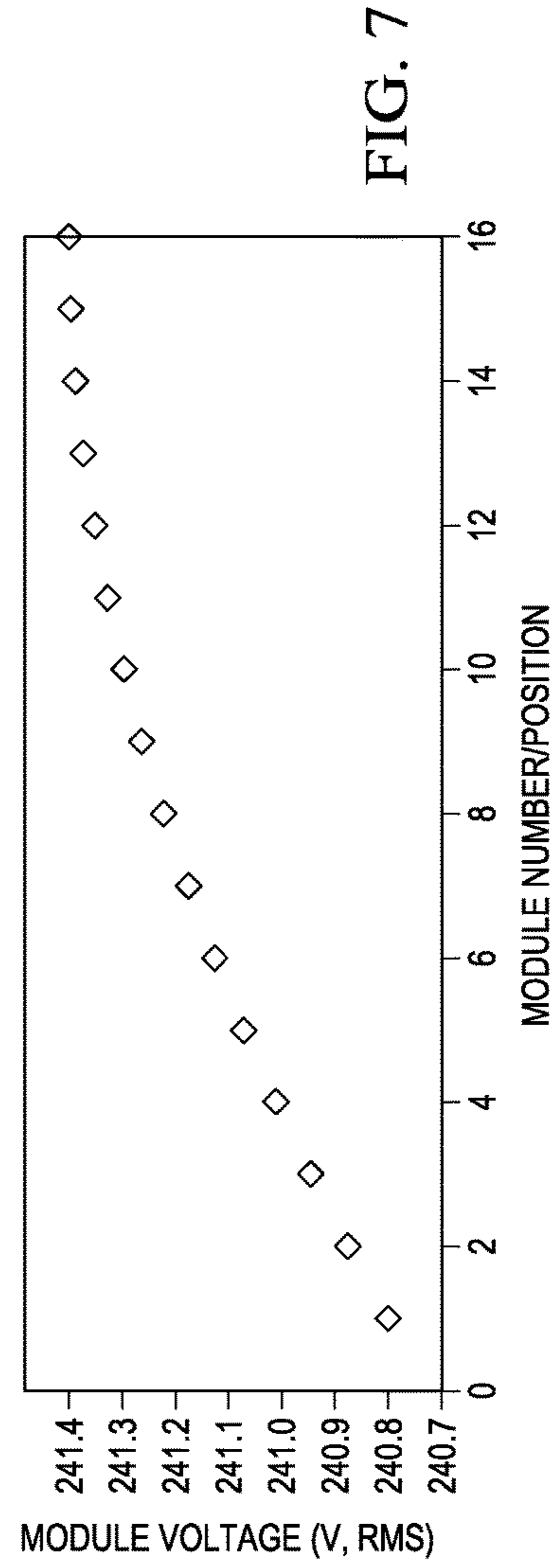


FIG. 7

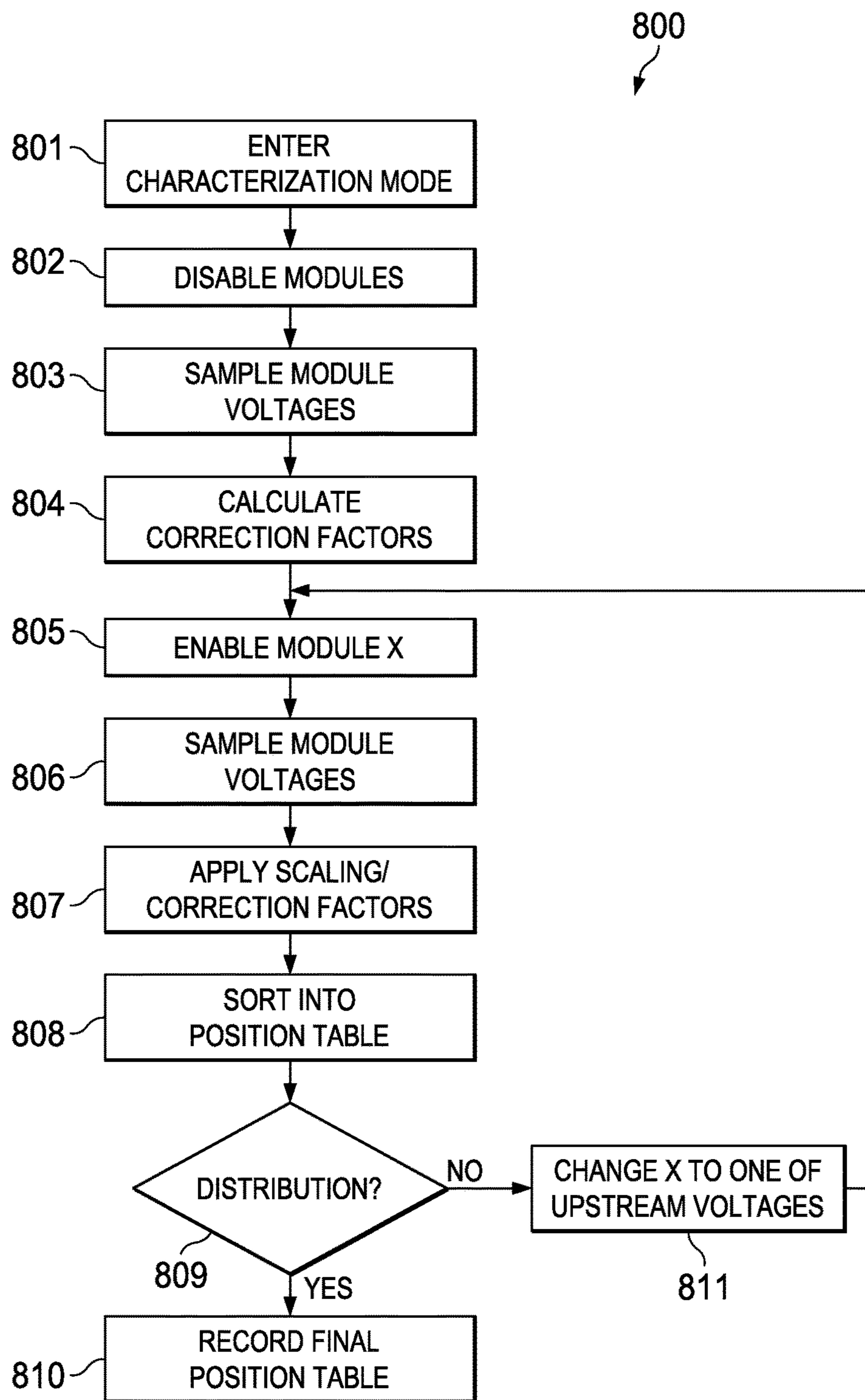


FIG. 8

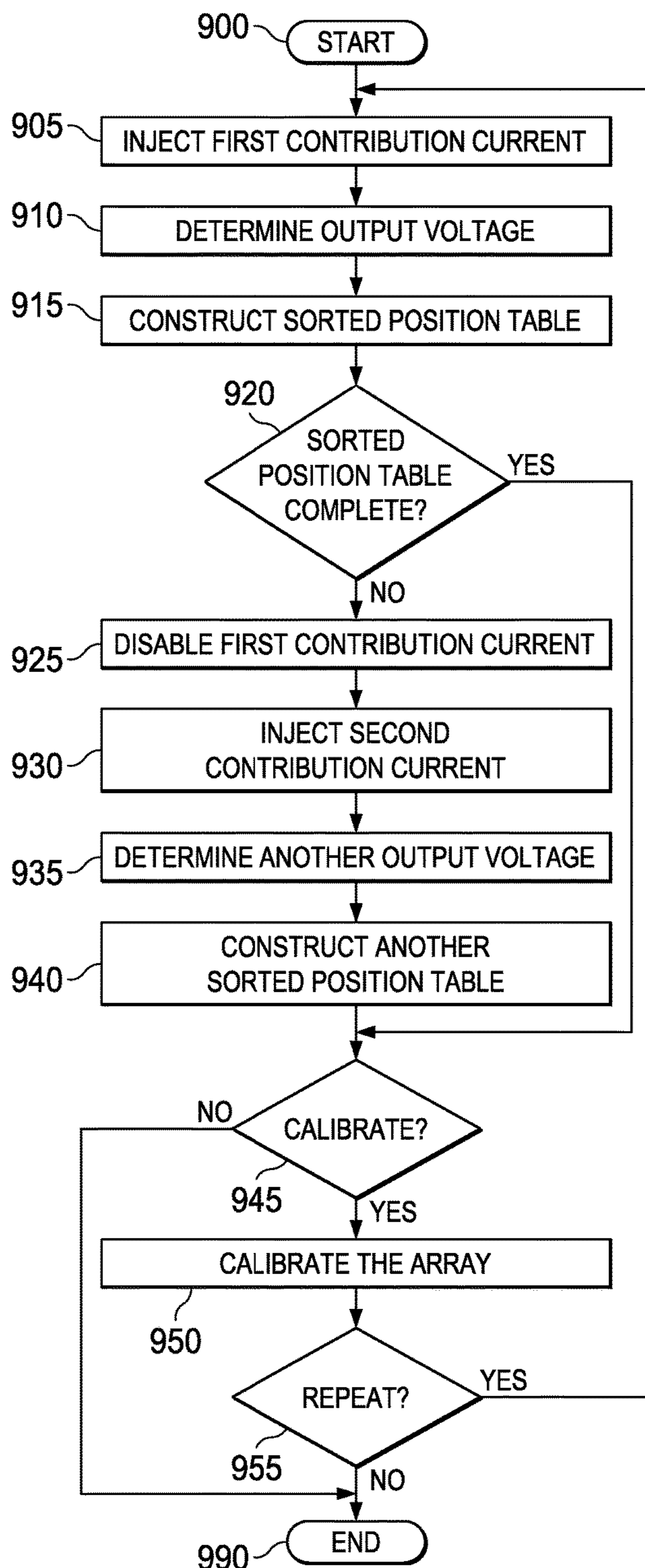


FIG. 9

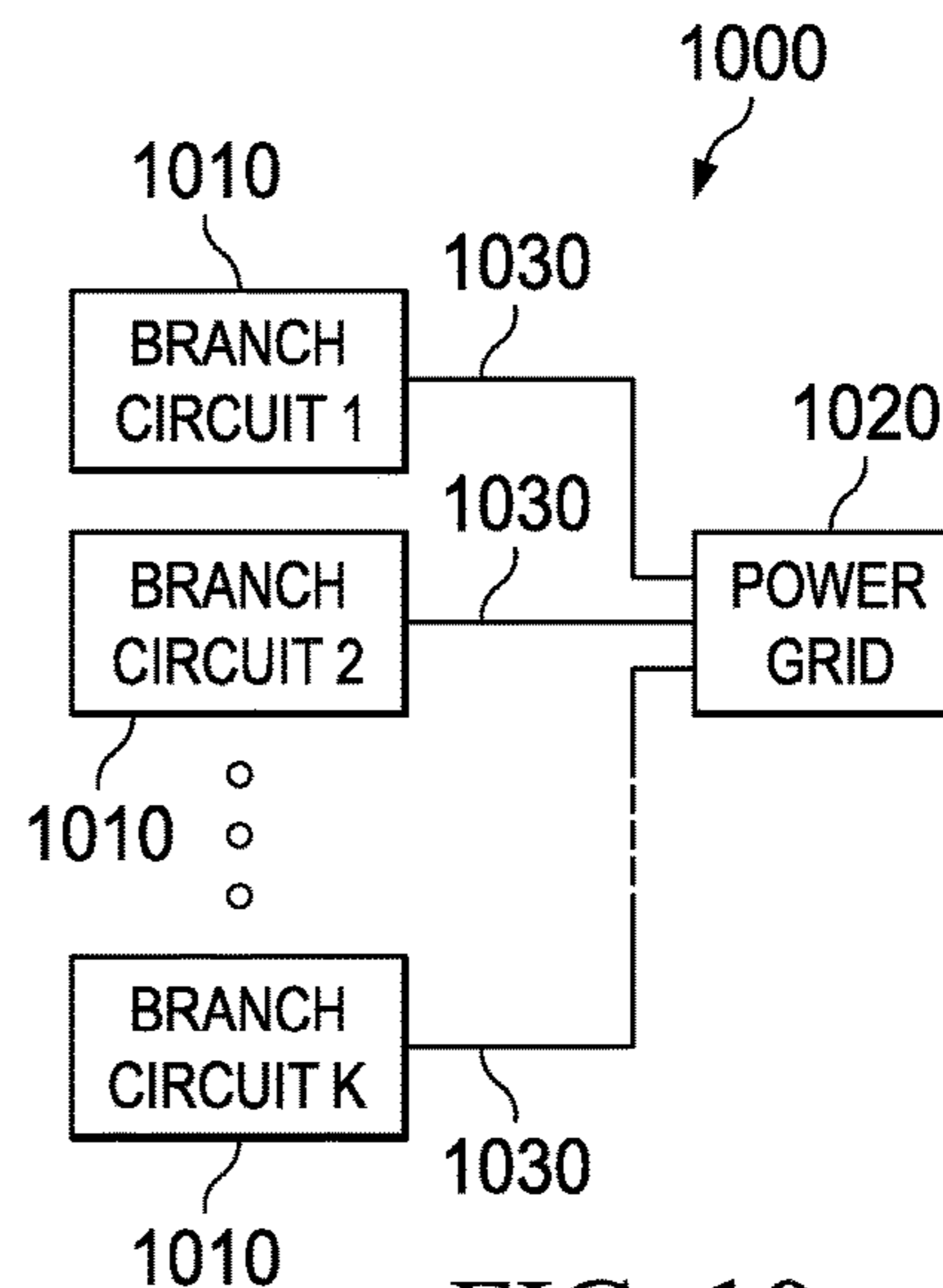


FIG. 10

ALTERNATIVE SOURCE MODULE ARRAY CHARACTERIZATION

This application claims the benefit of U.S. Provisional Application Ser. No. 62/002,885 entitled “Inverter Array Characterization,” filed May 25, 2014, which is incorporated herein by reference.

BACKGROUND

Power inverters convert a direct current (“DC”) power to an alternating current (“AC”) power. For example, some power inverters are configured to convert the DC power to an AC power suitable for supplying energy to an AC grid and, in some cases, an AC load coupled to the AC grid. One particular application for such power inverters is the conversion of DC power generated by an alternative energy source, such as photovoltaic cells (“PV cells” or “solar cells”), fuel cells, DC wind turbines, DC water turbines, and other DC power sources, to single-phase AC power for delivery to an AC grid at a grid frequency.

In an effort to increase the amount of AC power generated, a large number of power inverters may be used in a particular application. In some implementations, each power inverter is incorporated or otherwise associated with an alternative energy source to form an alternative energy source module. Such modules are typically located in remote or otherwise difficult to reach locations (e.g., a solar cell panel located on a roof).

A particular kind of an alternative energy source module is known as an alternating current photovoltaic (“ACPV”) module. An ACPV module includes at least a solar module (that produces DC power in response to sunlight), and an inverter that converts the DC power from the solar module to power grid compatible AC power. Such an inverter may be known as a microinverter.

When an array of at least two ACPV modules is installed on a roof, the array may be difficult to access at a later date for purposes of repair, maintenance, or augmentation of the array. An identifying mark, such as a serial number, will normally be associated with each ACPV module. Once the array has been installed, the identifying marks will generally not be visible or easily accessible.

BRIEF DESCRIPTION OF THE DRAWINGS

The concepts described herein are illustrated by way of example and not by way of limitation in the accompanying FIGURES. For simplicity and clarity of illustration, elements illustrated in the FIGURES are not necessarily drawn to scale. Where considered appropriate, reference labels have been repeated among the FIGURES to indicate corresponding or analogous elements.

FIG. 1 illustrates a simplified block diagram of an embodiment of a system for generating alternative energy;

FIG. 2 illustrates a simplified block diagram of an embodiment of the inverter of the system of FIG. 1;

FIGS. 3 and 4 illustrate simplified circuit diagrams of an embodiment of the inverter circuit of FIG. 2;

FIG. 5 illustrates a simplified block diagram of an embodiment of the inverter controller of the inverter of FIG. 2;

FIG. 6 illustrates a simplified block diagram of an embodiment of a branch circuit including a plurality of alternative energy source modules;

FIG. 7 illustrates a graphical representation of an embodiment of a distribution of the terminal voltages in the branch circuit of FIG. 6;

FIGS. 8 and 9 illustrate simplified flow diagrams of embodiments of methods for mapping relative positions of a plurality of alternative energy source modules; and

FIG. 10 illustrates a simplified block diagram of an embodiment of a plurality of branch circuits forming a multi-branch array.

Corresponding numerals and symbols in the different figures generally refer to corresponding parts unless otherwise indicated. The figures are drawn to clearly illustrate the relevant aspects of the preferred embodiments and are not necessarily drawn to scale

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

While the concepts of the present disclosure are susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and will be described herein in detail. It should be understood, however, that there is no intent to limit the concepts of the present disclosure to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives consistent with the present disclosure and the appended claims.

References in the specification to “one embodiment,” “an embodiment,” “an illustrative embodiment,” etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may or may not necessarily include that particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to engage such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

The disclosed embodiments may be implemented, in some cases, in hardware, firmware, software, or any combination thereof. The disclosed embodiments may also be implemented as instructions carried by or stored on a transitory or non-transitory machine-readable (e.g., computer-readable) storage medium, which may be read and executed by one or more processors. A machine-readable storage medium may be embodied as any storage device, mechanism, or other physical structure for storing or transmitting information in a form readable by a machine (e.g., a volatile or non-volatile memory, a media disc, or other media device).

In the drawings, some structural or method features may be shown in specific arrangements and/or orderings. However, it should be appreciated that such specific arrangements and/or orderings may not be required. Rather, in some embodiments, such features may be arranged in a different manner and/or order than shown in the illustrative FIGURES. Additionally, the inclusion of a structural or method feature in a particular FIGURE is not meant to imply that such feature is required in all embodiments and, in some embodiments, may not be included or may be combined with other features.

Turning now to FIG. 1, illustrated is a simplified block diagram of an embodiment of a system **100** for generating alternative energy. The system **100** may include an array **102** of alternative energy source modules (designated “ACPV module”) **104** and an inverter array gateway **112** electrically

coupled to each of the alternative energy source modules **104** via a conductor such as an alternating current (“AC”) power line cable **108**. The alternative energy source modules **104** may be configured to convert direct current (“DC”) power from an alternative energy source (e.g., a photovoltaic module) to AC power, which is supplied to a power grid via a service panel **110** via the AC power line cable **108**. In the illustrative embodiment, the alternative energy source modules **104** are embodied as photovoltaic modules configured to convert solar energy to AC power. However, in other embodiments, other types of alternative energy sources may be used such as, for example, fuel cells, DC wind turbines, DC water turbines, and/or other alternative energy sources. Additionally, although the illustrative array **102** includes two alternative energy source modules **104**, the array **102** may include more or fewer alternative energy source modules **104** in other embodiments.

The illustrative system **100** also includes the inverter array gateway **112**, which provides a communication portal to the array **102**. In use, each of the alternative energy source modules **104** is configured to communicate with the inverter array gateway **112** and/or other devices via the inverter array gateway **112**. To do so, as discussed in more detail below, the alternative energy source modules **104** may modulate information to be transmitted on to an output waveform, which may be an AC waveform, generated by each alternative energy source module **104**. Such modulation may include modulating information on to a modulation signal and/or a carrier signal of the output waveform as discussed below. It should be appreciated that because the output waveform of the alternative energy source modules **104** is used for such communications, additional communication circuitry (e.g., a power line carrier communication circuit) is not required in the alternative energy source modules **104**.

As discussed above, in the illustrative embodiment, the alternative energy source modules **104** may be embodied as photovoltaic modules coupled to or including solar panels. As such, each of the alternative energy source modules **104** may include a DC photovoltaic module (designated “DC PV module”) **120** and an inverter **122**. The DC photovoltaic module **120** may be embodied as one or more photovoltaic cells and is configured to deliver DC power to the inverter **122** in response to receiving an amount of sunlight. Of course, the DC power delivered by the DC photovoltaic module **120** is a function of environmental variables such as, without limitation, sunlight intensity, sunlight angle of incidence and temperature. The inverter **122** is configured to convert the DC power generated by the DC photovoltaic module **120** to AC power. In some embodiments, the inverter **122** and the DC photovoltaic module **120** are located in a common housing. Alternatively, the inverter **122** may include its own housing secured to the housing of the DC photovoltaic module **120**. Additionally, in some embodiments, the inverter **122** is separate from the housing of the DC photovoltaic module **120**, but located nearby.

Each of the illustrative inverters **122** may include a DC-to-AC inverter circuit (designated “inverter circuit”) **124** and an inverter controller **126**. The DC-to-AC inverter circuit **124** may be configured to convert the DC power generated by the DC photovoltaic module **120** to AC power at the power grid frequency. The operation of the inverter **122** may be controlled and monitored by the inverter controller **126**. The illustrative inverter controller **126** includes a processor **130** and a memory **132**. Additionally, the inverter controller **126** may include other devices commonly found in controllers which are not illustrated in FIG. 1 for clarity of description. Such additional devices may include,

for example, peripheral devices, data storage devices, input/output ports, and/or other devices.

The processor **130** of the inverter controller **126** may be embodied as any type of processor capable of performing the functions described herein including, but not limited to, a microprocessor, digital signal processor, microcontroller, or the like. The processor **130** is illustratively embodied as a single core processor, but may be embodied as a multi-core processor having multiple processor cores in other embodiments. Additionally, the inverter controller **126** may include additional processors having one or more processor cores in other embodiments.

The memory **132** of the inverter controller **126** may be embodied as one or more memory devices or data storage locations including, for example, dynamic random access memory devices (“DRAM”), synchronous dynamic random access memory devices (“SDRAM”), double-data rate synchronous dynamic random access memory device (“DDR SDRAM”), flash memory devices, and/or other volatile memory devices. The memory **132** is communicatively coupled to the processor **130** via a number of signal paths, such as a data bus, point-to-point connections, or other interconnects. Although only a single memory **132** is illustrated in FIG. 1, in other embodiments, the inverter controller **126** may include additional memory.

The inverter array gateway **112** may include a demodulation circuit **150** configured to demodulate the information transmitted by the alternative energy source modules **104** over the AC power line cable **108**. In the illustrative embodiment, the demodulation circuit **150** may include an amplifier **152**, that may receive a sensor signal from a current sensor **140** coupled to the AC power line cable **108**. The amplifier **152** may amplify and condition the sensor signal, which may be provided to a demodulator **154**. The demodulator **154** may demodulate information from the sensor signal and provide the demodulated information to a processor **156**, which may subsequently save the information in local or remote data storage, transmit the information to a remote device (e.g., a remote monitor computer), generate local or remote alarms (via an alarm circuit **159**), or take some other action in response to the information. The processor **156** may be embodied as any type of processor capable of performing the functions described herein including, but not limited to, a microprocessor, digital signal processor, microcontroller, or the like. Depending on the type of modulation used by the alternative energy source modules **104**, the demodulation circuit **150** may include an analog-to-digital converter (designated “ADC”) **158** in addition to, or in place of, the demodulator **154**. Regardless, each of the demodulators **154** and the analog-to-digital converters **158** are configured to supply the demodulated information to the processor **156**. As will become more apparent, the inverter array gateway **112** can selectively enable or disable the alternative energy source modules **104**, organize measured data therefrom into data structures (e.g., position tables), and communicate the resulting tables remotely (via a wired or wireless connection) to, without limitation, a mobile phone or a computer of a user.

In some embodiments, the system **100** may also include a maintenance tool **160**, which may be utilized by an installer or repairer of the alternative energy source modules **104**. Similar to the inverter array gateway **112**, the maintenance tool **160** is configured to communicate with the alternative energy source modules **104**. However, when the maintenance tool **160** is coupled to the AC power line cable **108**, a switch **164** of the service panel **110** may be opened to decouple the array **102** from the power grid. In such

embodiments, the alternative energy source modules **104** may discontinue generation of AC output power (e.g., by detecting an islanding condition). As such, the maintenance tool **160** and the alternative energy source modules **104** may utilize the AC power line cable **108** solely for communication purposes (i.e., not for delivery of power as normal) while the array **102** is disconnected from the power grid. In such circumstances, a communication protocol of higher bandwidth, relative to communication techniques using the AC power line cable **108** while AC output power is being supplied, may be used (e.g., a Modbus protocol). The maintenance tool **160** may include a communication circuit **162** to support such “off-line” communications with the alternative energy source modules **104**. As illustrated, the maintenance tool **160** may be located within or outside of the inverter array gateway **112**.

Turning now to FIG. 2, illustrated is a simplified block diagram of an embodiment of an inverter **122** of the system **100** of FIG. 1. In the simplified block diagram illustrated in FIG. 2, the inverter circuit **124** of the inverter **122** may include an input converter **200** electrically coupled to a DC bus **204** and an output converter **202** with an input electrically coupled to the DC bus **204**. Additionally, in some embodiments, the inverter circuit **124** may also include an input filter **210** electrically coupled to the input converter **200** and the DC photovoltaic module **120** and an output filter **212** electrically coupled to the output converter **202** and the service panel **110**.

In the illustrative embodiment, the input converter **200** may be embodied as a DC-to-DC converter configured to convert low voltage DC power to high voltage DC power. That is, the input converter **200** converts the DC power received from the DC photovoltaic module **120** to a high level DC voltage power, which is supplied to the DC bus **204**. The output converter **202** may be embodied as a DC-to-AC converter configured to convert the high voltage DC power from the DC bus **204** to AC power, which is supplied to the service panel **110**, and thereby the power grid at the grid frequency.

The inverter controller **126** may be electrically coupled to the input converter **200** and configured to control the operation of the input converter **200** to convert the low voltage DC power received from the DC photovoltaic module **120** to the high voltage DC power supplied to the DC bus **204**. Additionally, in some embodiments, the inverter controller **126** may control the operation of the input converter **200** based on a maximum power point tracking (“MPPT”) algorithm or methodology. To do so, the inverter controller **126** may provide a plurality of control signals to various circuits of the input converter **200**.

The inverter controller **126** may also be electrically coupled to the output converter **202** and configured to control operation of the output converter **202** to convert the DC power of the DC bus **204** to AC power suitable for delivery to the power grid via the service panel **110**. Additionally, as discussed in more detail below, the inverter controller **126** may be configured to control the operation of the output converter **202** so as to provide a test signal via an output waveform of the inverter circuit **124**. In particular, the inverter controller **126** may generate switch signals to control the operation of a plurality of switches of the output converter **202** to provide a test current (a contribution current) to the power grid via the service panel **110**.

Turning now to FIGS. 3 and 4, illustrated are simplified circuit diagrams of an embodiment of the inverter circuit **124** of FIG. 2. Beginning with FIG. 3, the input converter **200** may include an inverter circuit **300**, a transformer **302**,

and a rectifier circuit **304**. The inverter circuit **300** may be embodied as a DC-to-AC inverter circuit configured to convert the DC waveform supplied by the DC photovoltaic module **120**, via the input filter **210**, to an AC waveform delivered to a primary winding **360** of the transformer **302**. For example, the inverter circuit **300** may be illustratively embodied as a bridge circuit formed by a plurality of switches **350**, **352**, **354**, **356**. Each of the switches **350**, **352**, **354**, **356** may be configured to receive a corresponding control signal q_{IC1} , q_{IC2} , q_{IC3} , q_{IC4} , from the inverter controller **126** (illustrated in FIG. 2) to control an operation of the inverter circuit **300**. The inverter controller **126** may use pulse-width modulation (“PWM”) to control the switches **350**, **352**, **354**, **356** at a relatively high switching frequency (e.g., at a frequency such as, without limitation, 100 kilohertz (“kHz”) that is substantially higher than the AC grid frequency, which is typically 50 or 60 hertz (“Hz”)). As discussed above, the input converter **200** converts the DC waveform from the DC photovoltaic module **120** to a first AC waveform based on control signals received from the inverter controller **126**. In the illustrative embodiment, the inverter circuit **300** may be embodied as a full-bridge circuit, but other circuit topologies such as a half-bridge circuit may be used in other embodiments. Additionally, although each of the switches **350**, **352**, **354**, **356** is illustrated as metal-oxide semiconductor field-effect transistor (“MOSFET”) devices, other types of switches can be used in other embodiments.

The transformer **302** may be embodied as a two or more winding transformer having the primary winding **360** electrically coupled to the inverter circuit **300** and a secondary winding **362** coupled to the rectifier circuit **304**. The transformer **302** may be configured to convert the first AC waveform supplied by the inverter circuit **300** at the primary winding **360** to a second AC waveform at the secondary winding **362**. The first and second AC waveforms may have substantially equal frequencies and may or may not have substantially equal voltages. The illustrative transformer **302** includes the primary winding **360** electrically coupled to the inverter circuit **300** and the secondary winding **362** electrically coupled to the rectifier circuit **304**. The transformer **302** may provide galvanic isolation between the primary side circuitry (including DC photovoltaic module **120**) and the secondary side circuitry (including the DC bus **204**). The turns ratio of the transformer **302** may also provide voltage and current transformation between the first AC waveform at the primary winding **360** and the second AC waveform at the secondary winding **362**.

The rectifier circuit **304** may be electrically coupled to the secondary winding **362** of the transformer **302** and configured to rectify the second AC waveform to a DC waveform supplied to the DC bus **204**. In the illustrative embodiment, the rectifier circuit **304** may be embodied as a full-bridge rectifier formed from a plurality of diodes **370**, **372**, **374**, **376**. Again, in other embodiments, other circuit topologies and other components such as synchronous rectifiers may be used in the rectifier circuit **304**.

The DC bus **204** may be coupled to the rectifier circuit **304** of the input converter **200** and to the output converter **202**. The DC bus **204** may be configured to store energy from the input converter **200** and transfer energy to the output converter **202** as needed. To do so, the DC bus **204** may be maintained at a high voltage DC value relative to DC voltage values produced by the DC photovoltaic module **120** and may include a DC bus capacitor **380**. The particular value of capacitance of the DC bus capacitor **380** is dependent on the particular parameters of the inverter circuit **124**

such as the desired voltage level of the DC bus **204**, the expected requirements of the power grid, and/or the like.

As shown in FIG. 4, the output converter **202** may be electrically coupled to the DC bus **204** and configured to convert the DC bus waveform to the output AC waveform, which is filtered by the output filter **212**. The output converter **202** may include a DC-to-AC inverter circuit **400** configured to convert the DC waveform supplied by the DC bus **204** to an AC waveform delivered to the output filter **212**. For example, the inverter circuit **400** may illustratively be embodied as a bridge circuit formed by a plurality of switches **402**, **404**, **406**, **408**. Each of the switches **402**, **404**, **406**, **408** may be configured to receive a corresponding control signal q_{OC1} , q_{OC2} , q_{OC3} , q_{OC4} , from the inverter controller **126** to control operation of the output converter **202**. As discussed above, the inverter controller **126** may use PWM to control the switches **402**, **404**, **406**, **408** to generate a pulse width modulated AC waveform. Again, it should be appreciated that although the illustrative output converter **202** is embodied as a full-bridge circuit, other circuit topologies such as a half-bridge circuit may be used in other embodiments. Additionally, although each of the switches **402**, **404**, **406**, **408** is illustrated as a MOSFET device, other types of switches may be used in other embodiments.

The input filter **210** and output filter **212** may be configured to provide filtering functions of the DC input waveform from the DC photovoltaic module **120** and the AC output waveform to the power grid, respectively. The input filter **210** illustratively includes a filtering capacitor **390** and a filtering inductor **392**. However, other filtering components and topologies may be used in other embodiments. The output filter **212** may be configured to filter the output voltage by reducing the conducted interference and satisfying regulatory requirements. In the illustrative embodiment, the output filter **212** may include differential-mode inductors **420**, **422**, a line filter capacitor **424**, and common-mode inductors **426**, **428**. Again, however, other filtering component and topologies may be used in other embodiments.

Turning now to FIG. 5, illustrated is a simplified block diagram of an embodiment of the inverter controller **126** of the inverter **122** of FIG. 2. The inverter controller **126** may include various control modules to control the operation of the input converter **200** and the output converter **202**. With specific regard to the control of the output converter **202**, the inverter controller **126** may include processing circuitry **500** and output sense circuitry **502**, which provides various sensed signals to the processing circuitry **500**. The processing circuitry **500** may be embodied in, or otherwise include, the processor **130** and/or the memory **132** of the inverter controller **126** (see FIG. 1), as well as additional circuitry and/or devices. The output sense circuitry **502** may include a plurality of sensing circuits to sense various currents and voltages of the inverter **122** and/or power grid. In the illustrative embodiment, the output sense circuitry **502** may be configured to sense or calculate the local power grid line voltage V_{LINE_RMS} , the local grid phase (or phase angle of the local grid voltage) θ_{LINE} , and the output power P_{OUT} associated with the inverter **122**. However, in other embodiments, additional or other currents, voltages, and/or circuit characteristics may be sensed or otherwise measured by the output sense circuitry **502**.

The processing circuitry **500** may include a plurality of control modules, which may be embodied as firmware/software programs (e.g., stored in the memory **132**), discrete hardware circuitry, and/or a combination of hardware and software. In the illustrative embodiment, the processing circuitry **500** may include an output current controller **510**

and an output converter control module **512**. Of course, it should be appreciated that additional or other modules, functionality, and features may be included in the processing circuitry **500** depending on the particular implementation. Additionally, it should be appreciated that although the output current controller **510** and the output converter control module **512** are illustrated in FIG. 5 as separate modules, the functionality of any one or more thereof may be incorporated into another module of the processing circuitry **500**.

The output current controller **510** may be configured to generate command signals as a function of a plurality of other signals and/or characteristics of the inverter **122**. For example, in the illustrative embodiment, the output current controller **510** may generate a current command signal i_{OC}^* as a function of a bus voltage V_{BUS} (see FIG. 3) of the DC power bus **204**, the local power grid line voltage V_{LINE_RMS} , and the local grid phase θ_{LINE} . Of course, in other embodiments, the output current controller **510** may generate the current command signal i_{OC}^* based on additional or other signals of the inverter **122**. Additionally, although the command signal may be embodied as a current command signal i_{OC}^* in FIG. 5, the command signal may be embodied as a voltage command signal, a duty cycle command signal, or another type of command signal in other embodiments.

The output converter control module **512** may be configured to control the operation of the output converter **202**. To do so, the output converter control module **512** may be configured to generate the control signals q_{OC1} , q_{OC2} , q_{OC3} , q_{OC4} that control the operation of the switches **402**, **404**, **406**, **408** of the output converter **202**. In the illustrative embodiment, the output converter control module **512** may include a proportional-integral module (designated "PI") **520** configured to generate a duty cycle command signal d_{OC} based on the current command signal i_{OC}^* and a feedback signal of an output current i_{OC} of the inverter **122**. The duty cycle command signal d_{OC} may be provided to a pulse width modulation control module (designated "PWM") **522**, which generates the control signals q_{OC1} , q_{OC2} , q_{OC3} , q_{OC4} based on the duty cycle command signal d_{OC} . The output converter control module **512** may also include a pulse mode control module **530** configured to generate the control signals q_{OC1} , q_{OC2} , q_{OC3} , q_{OC4} that control the operation of the switches **402**, **404**, **406**, **408** when the output converter **202** operates in a pulse mode of operation. For a better understanding of an operation associated with the pulse mode control module **530**, see U.S. Pat. No. 8,284,574 entitled "Method and Apparatus for Controlling an Inverter using Pulse Mode Control," to Chapman, et al., issued Oct. 9, 2012, which is incorporated herein by reference. The output converter control module **512** may also perform various safety and/or quality verification checks on the inverter **122** such as ensuring that the output power remains within an acceptable range, protecting against anti-islanding conditions, and/or other functions.

Turning now to FIG. 6, illustrated is a simplified block diagram of an embodiment of a branch circuit (or an array) **600** including a plurality of alternative energy source modules **604**, numbered consecutively from 1 to N, that are connected via cable impedances **601**, also numbered consecutively from Z_1 to Z_N . The cable impedances **601** are depicted as resistances, but one of ordinary skill in the art would understand that the cable impedances **601** could also include inductances and capacitances. However, at the frequency of a power grid **610**, which is approximately 60 Hz in the United States, resistances would likely dominate the impedances. The power grid **610** provides a grid voltage V_{grid} and may include grid interconnection equipment such

as a service panel, a disconnect switch, surge protection, and power meters. The alternative energy source modules **604** may also contain module impedances **602**. The module impedances **602** are typically very high at 60 Hz, being much larger than the cable impedances **601**, and are typically dominated by the capacitances of “X capacitors” and/or “Y capacitors,” which are often used to reduce conducted emissions that may produce electromagnetic interference.

Each alternative energy source module **604** may provide a contribution current **603**, also designated i_1 to i_N , to a cable network including the cable impedances **601**. The contribution currents **603** sum to provide a branch current (designated “ i_{branch} ”) **605**. The contribution currents **603** and the branch current **605** are typically alternating currents that may or may not have a phase shift relative to the grid voltage V_{grid} of the power grid **610**. However, according to standards such as IEEE 1547, which is incorporated herein by reference, the power factor of each alternative energy source module **604** may be unity, meaning that the contribution currents **603** (and therefore the branch current **605**) are in phase with the grid voltage V_{grid} of the power grid **610**. As such, reading FIG. 6 from left to right, the peak or root mean square (“RMS”) values of the contribution currents **603** may be simply additive and accumulate as follows. The leftmost cable impedance **601** would conduct only i_N . The next-to-leftmost cable impedance **601** would conduct i_N+i_{N-1} . Likewise, the third-from-leftmost cable impedance **601** would conduct $i_N+i_{N-1}+i_{N-2}$, and so on.

Each cable impedance **601** in combination with its conducted current may contribute a voltage drop according to Ohm’s Law. The alternative energy source modules **604** may have corresponding terminal voltages **606**, also referred to as V_1 through V_N (wherein V_1 and V_N refer to terminal voltages for the first and Nth alternative energy source modules **604**, respectively). For example, the terminal voltage V_1 can be calculated as $V_1=V_{grid}+(i_1+i_2+\dots+i_N)\cdot Z_1$. Assuming the contribution currents **603** are positive or zero (that is, in phase with the grid voltage V_{grid}), the terminal voltage V_1 may be greater than or equal to the grid voltage V_{grid} of the power grid **610**. Likewise, the terminal voltage V_2 can be calculated as $V_2=V_1+(i_2+i_3+\dots+i_N)\cdot Z_2$, wherein V_2 , i_2 and Z_2 represent a terminal voltage, a contribution current and a cable impedance, respectively, of a second alternative energy source module **604**. As such, the terminal voltages relate according to $V_2\geq V_1$. Likewise, all the terminal voltages V_1 through V_N may be similarly calculated and the terminal voltages relate according to $V_N\geq V_{N-1}\geq\dots\geq V_1\geq V_{grid}$. As such, the relative terminal voltages V_1 through V_N can be used to indicate the relative position of a particular alternative energy source module **604** in the branch circuit **600**.

Note that the cable impedances **601** may or may not be equal, although in systems connected with prefabricated cables, the impedances Z_2 through Z_N may be approximately equal. In that case, the impedance Z_1 may include the prefabricated cable impedance as well as the impedance of potentially lengthy wires that connect the branch circuit **600** to the power grid **610**. This potentially lengthy connection is sometimes referred to as a “whip cable.” As such, the impedance Z_1 is not only the highest impedance, but it also conducts the full branch current **605** and, therefore, has the largest voltage drop.

Turning now to FIG. 7 illustrated is a graphical representation of an embodiment of a distribution of the terminal voltages **606** in the branch circuit **605** of FIG. 6. The plot of a monotonic order of the terminal voltages **606** (designated

“Module Voltage” in volts, root mean square (“V”, RMS)) versus the position (designated “Module Number/Position”) of the alternative energy source modules **604** assumes that the impedances Z_2 through Z_N are five milliohms (“mΩ”), the impedance Z_1 is 50 mΩ, the grid voltage V_{grid} is 240 Vrms, and the contribution current **603** of each alternative energy source module **604** is one ampere.

As apparent from FIG. 7, the terminal voltages **606** measured by, for instance, an inverter controller (see, e.g., the inverter controller **126** of FIG. 5) may be compared to infer the relative position of the alternative energy source modules **604** in the branch circuit **600**. However, the contribution currents **603** from each alternative energy source module **604** are unlikely to be equal and, therefore, the actual plot of the terminal voltages **606** versus position in the branch circuit **600** will generally not be as smooth as that shown in FIG. 7. The terminal voltages **606** should, nonetheless, be monotonically increasing with position.

More generally, one can conduct a circuit analysis to determine that the relationship of the terminal voltages **606** to the contribution currents **603** and the cable impedances **601** can be expressed as a matrix equation $v=Zi+[1\ 1\ 1\ \dots\ 1]^T V_{rms}$. In this equation, “v” is a vector of the terminal voltages **606**, “i” is a vector of the contribution currents **603**, and Z is a matrix of impedances (e.g., cable impedances **601**). During normal operation, the alternative energy source modules **604** may produce the contribution currents **603** in response to their available power (e.g., from sunlight) and in response to conditions of the power grid **610**. The alternative energy source modules **604**, however, can be placed into a characterization mode via commands from the inverter array gateway (see, e.g., the inverter array gateway **112** of FIG. 1). In the characterization mode, for example, the inverter array gateway may specify that a subset (perhaps just one) of alternative energy sources modules **604** is enabled while the remaining alternative energy source modules **604** are disabled. In doing so, for instance, the output current controller **510** of the inverter controller **126** (see FIG. 5) may enable the output current control of the subset of alternative energy source modules **604** and disable the output current control of the remaining alternative energy source modules **604**.

In such a situation, some or all of the contribution currents **603** in the vector i may be zero. If only one contribution current **603** is enabled (or injected), then variation in the vector v may solely be due to that one contribution current **603**. More specifically, if a contribution current I_M for an Mth alternative energy sources module **604** is enabled ($1<M<N$), then one would expect to see a distribution of voltage rises in the terminal voltages **606** that are numbered V_1 through V_M and nearly a constant voltage in the terminal voltages **606** that are numbered V_{M+1} through V_N . Indeed, one would expect that $V_M=V_{M+1}=V_{M+2}=\dots=V_N$ since there would be substantially no current flowing in the cable impedances **601** beyond V_M .

Note that the inverter controller **126** of each alternative energy source module **604** may be equipped with the output current controller that senses the local power grid line voltage V_{LINE_RMS} at its output terminals, which is substantially equal to the terminal voltage **606** for a given alternative energy source module **604**. Via an inverter array gateway **112**, the alternative energy source modules **604** can report their measurements of the local power grid line voltage V_{LINE_RMS} such that inverter array gateway becomes aware of all the terminal voltages **606**. Likewise, each alternative energy source module **604** may also report other metrics such as its output power, the contribution current **603**, serial number, and fault codes, if any.

11

By enabling one alternative energy source module **604** and collecting measurements of all the terminal voltages **606**, the inverter array gateway **112** can sort the terminal voltages **606** and create a first list from least to greatest in a data structure such as a sorted position table. The inverter array gateway **112** can also sort the change in the terminal voltages **606** and create a first from least to greatest in the sorted position table. By looking at the changes rather than the absolute measurements, the inverter array gateway **112** may reduce (e.g., minimize) the effect of scaling errors due to tolerance of the measurement circuits of the alternative energy source modules **604**. Such a first list from least to greatest of the sorted position table may serve as a proxy for the positions of the alternative energy source modules **604** in the branch circuit **600**. It should be understood that the data structure may be embodied in other representations such as a map or graph in addition to the table discussed herein to delineate a relative position of the alternative energy source modules **604**.

As noted above, if only one contribution current **603** is enabled, then some terminal voltages **606** may be substantially equal, meaning they are located “upstream” from the enabled contribution current **603**. This means that in the first list from least to greatest, it is uncertain where to place such alternative energy source module **604**. To further ascertain the positions of the alternative energy source modules **604** having substantially equal terminal voltages **606**, one can repeat the above process for a different contribution current **603** by first disabling all alternative energy source modules **604** then enabling a contribution current **603** of one of the alternative energy source modules **604**, which we will label module P, that is not in the first “M” modules from the first list from least to greatest. Likewise, a second list from least to greatest can be formed such that alternative energy source modules **604** numbered 1 through P should show a distribution of terminal voltages **606** and alternative energy source modules **604** P+1 through N should show a substantially equal terminal voltage **606**. This process can be repeated as many times as necessary until a final list from least to greatest of the sorted position table has been obtained in which all the terminal voltages **606** 1 through N are distributed and not substantially equal. This final list from least to greatest of the sorted position table represents the relative positions of alternative energy source modules **604** within the branch circuit **600**.

The voltage measurements of the terminal voltages **606** are generally prone to some measurement error. Since the difference between any two terminal voltages **606** may be small, measurement error can cause the sorting to be inaccurate. One source of error is simply precision and drift in voltage sensors. Another source of error is that the terminal voltages **606** could be sampled at different times.

One way to correct for sensor error is to have the inverter array gateway **112** disable all the alternative energy source modules **604** and to sample all the terminal voltages **606**. In this circumstance, all the terminal voltages **606** should be substantially equal as there should be no significant current flowing in the cable impedances **601**. These disabled-state measurements of the terminal voltages **606** can be re-scaled or otherwise re-calibrated such that they are all substantially equal. These scaling factors may be recorded and applied to future measurements of the terminal voltages **606**.

Differences in sampling times of the terminal voltages **606** can occur due to serial communications that occur between the alternative energy source modules **604** and the inverter array gateway **112**. That is, the inverter array gateway **112** may “poll” the alternative energy source mod-

12

ules **604** during a polling cycle. If the alternative energy source modules **604** report their most recent sampling of the terminal voltages **606**, they may be reporting voltages that are seconds or minutes apart in time. One way to counteract this may be to configure the inverter array gateway **112** and the alternative energy source modules **604** with a “snap” command. The snap command may be issued from the inverter array gateway **112** and broadcast to all of the alternative energy source modules **604**. Upon receiving the snap command, each alternative energy storage module **604** may immediately sample its terminal voltage **606** and store it for later download. At a later time, the inverter array gateway **112** may then poll the alternative energy source modules **604** and recall the snapped voltage measurements of the terminal voltages **606**. In this way, the terminal voltages **606** may be sampled at approximately the same time.

Turning now to FIGS. **8** and **9**, illustrated are simplified flow diagrams of embodiments of methods for mapping relative positions of a plurality of alternative energy source modules. While the methods may be performed by an inverter array gateway, other equipment that has access to the array or to the inverter array gateway may perform the method **800** as well. Additionally, ones of the aforementioned steps of the respective methods may be omitted or re-ordered, or other steps may be added depending on the application therefor. Beginning with FIG. **8**, the method **800** commences by entering a characterization mode in a step or module **801** followed by disabling the alternative energy source modules in a step or module **802**. Then, the terminal (or module) voltages for the alternative energy source modules are sampled in a step or module **803**, optionally using the snap technique described above. At this point, the sampled terminal voltages would ideally be equal, but due to measurement and timing errors the terminal voltages will generally only be approximately equal.

Therefore, in a step or module **804** the sampled terminal voltages are used to calculate correction factors. Then, a loop is entered wherein an alternative energy source module (designated “X”) is enabled one at a time in a step or module **805**. The terminal voltages are sampled in a step or module **806** and corrected, in a step or module **807**, by applying a scaling/correction factor. After the correction, the terminal voltages are sorted into a data structure such as a position table from least to greatest in a step or module **808**. This table forms the basis of the alternative energy source module position within a branch circuit (see, e.g., the branch circuit **600** of FIG. **6**). In a decisional step or module **809**, a determination is made whether the terminal voltages of the alternative energy source modules show a distribution throughout the branch circuit. For instance, does the distribution indicate that the alternative energy source module X is last in the branch circuit. If so, then the method records the final sorted position table for the alternative energy source modules in the branch circuit in a step or module **810** and the method **800** concludes. If not, then in a step or module **811**, the alternative energy source module X is changed to a different value that is chosen among the non-distributed terminal voltages and the method **800** returns to the step or module **805**.

Turning now to FIG. **9**, the method for mapping relative positions of a plurality of alternative energy source modules begins at a start step or module **900**. The method continues by injecting a first contribution current (e.g., the contribution current **603** described with respect to FIG. **6**) into a power grid by a first alternative energy source module of the plurality of alternative energy source modules at a step or

module **905**. The method continues with determining an output voltage (e.g., the terminal voltage **606** described with respect to FIG. **6**) for ones of or each of the plurality of alternative energy source modules for instance, substantially simultaneously, at a step or module **910**.

The first alternative energy source module can modulate an output voltage waveform coupled to the power grid to report the output voltage for the first alternative energy source module. The first alternative energy source module can also modulate an output voltage waveform coupled to the power grid to report at least one of an output power, a serial number, a fault code and the first contribution current for the first alternative energy source module.

The method then constructs a data structure such as a sorted position table of the relative positions of the plurality of alternative energy source modules employing the output voltage for ones of or each of the plurality of alternative energy source modules in accordance with, for instance, the graphical representation of FIG. **7**, in a step or module **915**. An inverter array gateway (such as the inverter array gateway **112** introduced in FIG. **1**) in communication with of the plurality of alternative energy source modules may construct the sorted position table. The sorted position table can provide a monotonic order of the output voltage for ones of or each of the plurality of alternative energy source modules. The sorted position table can be constructed by employing a change in the output voltage for ones of or each of the plurality of alternative energy source modules. The sorted position table may include positioning a second alternative energy source module of the plurality of alternative energy source modules upstream of the first alternative energy source module when the output voltage of the first alternative energy source module is substantially equal to the output voltage of the second alternative energy source module.

In a decisional step or module **920**, the method determines if the sorted position table is complete. If the sorted position table is not complete, the method continues with disabling the first contribution current in a step or module **925** and injecting a second contribution current into the power grid by a second alternative energy source module of the plurality of alternative energy source modules in a step or module **930**. In a step or module **935**, the method determines another output voltage for ones of or each of the plurality of alternative energy source modules, and then constructs another sorted position table of the relative positions of the plurality of alternative energy source modules employing the another output voltage for ones of or each of the plurality of alternative energy source modules in a step or module **940**.

Thereafter, or if the sorted position table is complete pursuant to the decisional step or module **920** above, the method determines if the array including the plurality of alternative energy source modules should be calibrated in a decisional step or module **945**. If the array should be calibrated, the method continues by disabling the plurality of alternative energy source modules and calibrating the output voltage for the plurality of alternative energy source modules in a step or module **950**. It should be noted that the calibration step can also be performed at other times within the process and often at the beginning to ensure that the plurality of alternative energy source modules are calibrated before mapping the relative positions thereof. Then, it is determined if the method should be repeated in a step or module **955**. If the method should be repeated, the method returns to the step or module **905** to start over again. If the array should not be calibrated and the method should not be

repeated pursuant to the decisional steps or modules **945**, **955**, respectively, the method is complete in an end step or module **960**. It should be noted, that the method may also include detecting a failure by observing changes over time of an impedance matrix representing conductors coupling the plurality of alternative energy source modules to the power grid at any time or throughout the process described above.

Turning now to FIG. **10**, illustrated is a simplified block diagram of an embodiment of a plurality of branch circuits **1010** forming a multi-branch array **1000**. The multi-branch array **1000** of a plurality of branch circuits **1010** may be connected to a power grid **1020**. The connections to power grid **1020** may occur via conductors such as whip cables **1030**. Note that each whip cable **1030** may include a plurality of conductors (such as line 1, line 2, ground, and neutral for split-phase 240 VAC, 60-Hz power grids). The whip cables **1030** are often threaded through conduit from a rooftop to a service panel. The whip cables **1030** may include a portion of the rightmost cable impedance **601** discussed with respect to FIG. **6**. Each branch circuit **1010** may effectively be connected in parallel to the power grid **1020** via ends of the whip cables **1030** and are fed with the same voltage.

The methods discussed above can be extended to the multi-branch array **1000**. With reference to FIG. **6**, a single branch circuit **600** may be necessarily limited by the current rating of the circuit breakers and wires involved. For example, a 20 ampere (“A”) circuit breaker connected to the 240 volts alternating current (“VAC”), split-phase system may be limited to 80 percent of (20 A)(240 V) of power capability, per the U.S. National Electric Code. If each alternative energy source module **604** is rated for 240 watts (“W”), this limits each branch circuit **600** to 16 alternative energy source modules **604** that can individually provide contribution currents **603** up to one ampere each.

One of ordinary skill in the art would recognize that the approach can be extended to a plurality of branch circuits **1010** connected to the same power grid **1020**. In the case of the plurality of branch circuits **1010**, when a single alternative energy source module is enabled, the terminal voltages of only one branch circuit **1010** may increase. All terminal voltages not exhibiting voltage rise would be considered inhabitants of other branch circuits **1010** and can be discarded from the sorting of a first sorted position table. One need only repeat the methods for each branch circuit **1010** to fill in the sorted position tables therefor.

After obtaining the data structure such as the sorted position tables for all the branch circuits **1010**, the data may be used to automatically populate a graphical user interface depicting the alternative energy source modules along with their serial numbers or other available information. The graphical user interface may be accessible from the inverter array gateway via the Internet or via direct connection thereto using a wired connection such as “Cat-5” cable, serial communications such as RS-485, and/or local wireless communications such as “Bluetooth” or “WiFi.” For example, one may access the graphical user interface with a mobile phone or tablet computer via Bluetooth connections to inspect the populated array layout. Typically, through this graphical user interface, one would be able to reposition the depictions of the alternative energy source modules so that they visually line up with a known actual or desired orientation. In any case, the connections between the depictions of the alternative energy source modules are preserved per the data of the sorted position tables.

In addition to the automated array mapping method described above, further characterization of an array is possible via analysis of the measured terminal voltages. The impedance matrix Z discussed above can be calculated by utilizing power data, branch current data, and terminal voltage data. Furthermore, if it is known that at least some cable impedances are the result of prefabricated cables, then those cable impedances can be known in advance of installation. The determination of the impedance matrix Z , or specific elements thereof, can be done periodically to determine if changes are occurring in the array. Such changes could be indicative of failures of alternative energy source modules, loose connections, and the like. Information pertaining to the impedance matrix Z could be use advantageously to those conducting maintenance or repairs on the array by aiding them in isolating problems specific to some alternative energy source modules or some cable impedances. Such an analysis can be done remotely via the Internet or locally using a maintenance tool.

As a further aid in array characterization, module impedances (e.g., module impedance **602** of FIG. **6**) may also be favorably utilized. In a condition wherein all alternative energy source modules are disabled, branch circuit and/or array impedances may be dominated by the relative high module impedances. Since the module impedances can be known in advance by the manufacturer, a measurement of the branch circuit impedance may be indicative of the total count of the alternative energy source modules connected to a power grid. For example, if a single module impedance is ten kilo-ohms at a given frequency, then if there are 20 alternative energy source modules in the array, one would expect to measure a total impedance of approximately 500 ohms since the impedances are approximately in parallel (neglecting the small cable impedances). If the measured impedance differs significantly from 500 ohms, in this example, then one would expect that there may be a failed connection or a failed alternative energy source module in the branch circuit. A maintenance tool may be used to provide test signals to the array or to one or more branch circuits to make the array impedance determination. Thus, the collective module impedances for a branch circuit or array may be measured via an inverter array gateway or maintenance tool, and based on the collective module impedance measurement a determination is made whether the array has a failure.

Thus, a system including an array of a plurality of alternative energy source modules (see, e.g., the array **102** of the plurality of alternative energy source modules **104** of FIG. **1**) and an inverter array gateway (see, e.g., the inverter array gateway **112** of FIG. **1**) has been introduced herein. In one embodiment, a first alternative energy source module may be configured to inject a first contribution current (e.g., the contribution current **603** described with respect to FIG. **6**) into a power grid (e.g., the power grid **610** of FIG. **6**) and determine an output voltage (e.g., the terminal voltage **606** described with respect to FIG. **6**) resulting therefrom. The first alternative energy source module may be configured to determine the output voltage thereof in response to a command to the plurality of alternative energy source modules from the inverter array gateway. The first alternative energy source module may further be configured to modulate an output voltage waveform coupled to the power grid to report the output voltage for the first alternative energy source module. The first alternative energy source module may further be configured to modulate an output voltage waveform coupled to the power grid to report at least one of an

output power, a serial number, a fault code or the first contribution current for the first alternative energy source module.

The inverter array gateway may be configured to receive an output voltage for ones of or each of the plurality of alternative energy source modules, and construct a data structure such as a sorted position table of relative positions of the plurality of alternative energy source modules employing the output voltage for ones of or each of the plurality of alternative energy source modules in accordance with, for instance, the graphical representation of FIG. **7**. The inverter array gateway may be configured to construct the sorted position table by providing a monotonic order of the output voltage for ones of or each of the plurality of alternative energy source modules. The inverter array gateway may also be configured to construct the sorted position table by employing a change in the output voltage for ones of or each of the plurality of alternative energy source modules. The inverter array gateway may also be configured to construct the sorted position table by identifying a position of a second alternative energy source module of the plurality of alternative energy source modules upstream of the first alternative energy source module when the output voltage of the first alternative energy source module is substantially equal to the output voltage of the second alternative energy source module.

Under certain circumstances, the system may perform a second iteration to map relative positions of the plurality of alternative energy source modules. Thus, the first alternative energy source module may be configured to disable the first contribution current and a second alternative energy source module of the plurality of alternative energy source modules is configured to inject a second contribution current into the power grid and determine another output voltage resulting therefrom. The inverter array gateway may be configured to receive another output voltage for ones of or each of the plurality of alternative energy source modules and construct another sorted position table of the relative positions of the plurality of alternative energy source modules employing the another output voltage for ones of or each of the plurality of alternative energy source modules.

At any time in the process, the system can calibrate the plurality of alternative energy source modules by disabling the plurality of alternative energy source modules, and calibrating the output voltage for the plurality of alternative energy source modules. In view of fault analysis, the inverter array may also be configured to detect a failure by observing changes over time of an impedance matrix representing conductors coupling the plurality of alternative energy source modules to the power grid.

As provided herein, technologies for characterizing certain aspects of an array of alternative energy source modules are disclosed. The technologies may include determining the relative position of the alternative energy source modules in the array and characterizations of the module electrical network of the array. The technologies may also include utilizing the characterizations to diagnose failure or improper installation conditions. The technologies may further include providing data of the relative positions and characterizations to a user via an inverter array gateway that may communicate wirelessly or as wired with other computing devices or maintenance tools.

For a better understanding of power supplies, see "Modern DC-to-DC Switchmode Power Converter Circuits," by Rudolph P. Severns and Gordon Bloom, Van Nostrand Reinhold Company, New York, N.Y. (1985) and "Principles of Power Electronics," by J. G. Kassakian, M. F. Schlecht,

and G. C. Verghese, Addison-Wesley (1991). The aforementioned references are incorporated herein by reference in their entirety.

Also, although the present embodiments and advantages have been described in detail, it should be understood that various changes, substitutions, and alterations can be made herein without departing from the spirit and scope of the claims. For example, many of the processes discussed above can be implemented in different methodologies and replaced by other processes, or a combination thereof.

Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods, and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present disclosure. Accordingly, claims on embodiments are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

The invention claimed is:

1. A method for mapping relative positions of a plurality of alternative energy source modules, comprising:

injecting only a first contribution current into a power grid by a first alternative energy source module of said plurality of alternative energy source modules;

determining an output voltage for each of said plurality of alternative energy source modules; and

constructing a data structure indicative of said relative positions of said plurality of alternative energy source modules employing said output voltage for ones of said plurality of alternative energy source modules.

2. The method as recited in claim **1**, further comprising: disabling said first contribution current;

injecting a second contribution current into said power grid by a second alternative energy source module of said plurality of alternative energy source modules;

determining another output voltage for each of said plurality of alternative energy source modules; and

constructing another data structure of said relative positions of said plurality of alternative energy source modules employing said another output voltage for ones of said plurality of alternative energy source modules.

3. The method as recited in claim **1** wherein said first alternative energy source module modulates an output voltage waveform coupled to said power grid to report said output voltage for said first alternative energy source module.

4. The method as recited in claim **1** wherein said first alternative energy source module modulates an output voltage waveform coupled to said power grid to report at least one of an output power, a serial number, a fault code or said first contribution current for said first alternative energy source module.

5. The method as recited in claim **1** wherein said constructing said data structure employs a change in said output voltage for ones of said plurality of alternative energy source modules.

6. The method as recited in claim **1** wherein said constructing said data structure comprises positioning a second alternative energy source module of said plurality of alternative energy source modules upstream of said first alter-

native energy source module when said output voltage of said first alternative energy source module is substantially equal to said output voltage of said second alternative energy source module.

7. The method as recited in claim **1** wherein said constructing said data structure provides a monotonic order of said output voltage for ones of said plurality of alternative energy source modules.

8. The method as recited in claim **1**, further comprising: disabling said plurality of alternative energy source modules; and calibrating said output voltage for said plurality of alternative energy source modules.

9. The method as recited in claim **1** wherein said determining said output voltage for each of said plurality of alternative energy source modules occurs substantially simultaneously.

10. The method as recited in claim **1**, further comprising detecting a failure by observing changes over time of an impedance matrix representing conductors coupling said plurality of alternative energy source modules to said power grid.

11. A system, comprising: an array of a plurality of alternative energy source modules including a first alternative energy source module configured to inject only a first contribution current into a power grid and determine an output voltage resulting therefrom; and

an inverter array gateway configured to: receive an output voltage for each of said plurality of alternative energy source modules, and construct a data structure of relative positions of said plurality of alternative energy source modules employing said output voltage for ones of said plurality of alternative energy source modules.

12. The system as recited in claim **11** wherein said first alternative energy source module is configured to disable said first contribution current and a second alternative energy source module of said plurality of alternative energy source modules is configured to inject a second contribution current into said power grid and determine another output voltage resulting therefrom, said inverter array gateway being configured to receive another output voltage for ones of said plurality of alternative energy source modules and construct another data structure of said relative positions of said plurality of alternative energy source modules employing said another output voltage for ones of said plurality of alternative energy source modules.

13. The system as recited in claim **11** wherein said first alternative energy source module is further configured to modulate an output voltage waveform coupled to said power grid to report said output voltage for said first alternative energy source module.

14. The system as recited in claim **11** wherein said first alternative energy source module is further configured to modulate an output voltage waveform coupled to said power grid to report at least one of an output power, a serial number, a fault code or said first contribution current for said first alternative energy source module.

15. The system as recited in claim **11** wherein said inverter array gateway is configured to construct said data structure by employing a change in said output voltage for ones of said plurality of alternative energy source modules.

16. The system as recited in claim **11** wherein said inverter array gateway is configured to construct said data structure by identifying a position of a second alternative energy source module of said plurality of alternative energy source

modules upstream of said first alternative energy source module when said output voltage of said first alternative energy source module is substantially equal to said output voltage of said second alternative energy source module.

17. The system as recited in claim 11 wherein said inverter array gateway is configured to construct said data structure by providing a monotonic order of said output voltage for ones of said plurality of alternative energy source modules. 5

18. The system as recited in claim 11 wherein said inverter array gateway is further configured to: 10

disable said plurality of alternative energy source modules; and

calibrate said output voltage for said plurality of alternative energy source modules.

19. The system as recited in claim 11 wherein said first alternative energy source module is configured to determine said output voltage thereof in response to a command to said plurality of alternative energy source modules from said inverter array gateway. 15

20. The array as recited in claim 11 wherein said inverter array gateway is further configured to detect a failure by observing changes over time of an impedance matrix representing conductors coupling said plurality of alternative energy source modules to said power grid. 20

* * * * *

25